Low Level RF (WP9)

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for the LLRF Team

Objectives

- Advance RF Control Technology in the areas of hard-ware and software to meet the requirements for linear collider and X-ray FEL. Focus is on
  - compatibility with tunnel installation (low maintenance, radiation resistance)
  - high degree of automation for large scale system, operability
  - reliability and availability optimization and cost reduction
  - technical masterpiece, pushing the envelope of performance

Tasks

- Single Bunch Transient Detection
- Automation of LLRF Control
- Control Optimisation
- Cost and Reliability
- Multichannel Downconverter
- Third Generation RF Control
- Stable M.O. and Frequency Distribution
- Data Management Development
- RF Gun Control
- Radiation Effects on Electronics

Single Bunch Transient Detection

- Detection of transient of single bunch (8 nC)
  - with magnitude of about 1e-3
  - with a resolution of a few percent in amplitude and few degrees in phase.
- This requires development of new hardware (microwave, analog, digital)
  - with high bandwidth and low noise.
- Conceptual idea is to subtract delayed probe signal from original probe signal so that nulled difference signal can be amplified at 1.3 GHz.
  - Transient is detected with high speed I/Q demodulator.

Design optimization cost and reliability

- Reduce cost of LLRF system by application of state of the art COTS.
- This leads to compact design.
- Addresse hardware and software issues.
- Reliability studies include electronic components, packaging including connectors, thermal and radiation effects.
- Protoype of critical components is produced and studied in environmental chamber (temperature, vibration, electromagnetic noise).

Highly stable frequency distribution

- The XFEL and Linear Collider require a high phase stable reference to
  - ensure that rf signals of laser, rf gun, and accelerating cavities are synchronized to better than 100 fs (short term) and 1 ps (long term)
- Must provide the necessary frequencies at many rf stations with the correct power level
- The proposed approach combines
  - a coaxial distribution system
  - with a fiber optic monitoring system.
- Goal is the design, construction and evaluation of such a system with real beam.

3rd generation rf control (FPGA)

- Digital rf feedback systems for superconducting cavities require high speed real time data processing
  - from a large number (up to 128) of ADC input channels and a smaller number (up to 64) DAC output channels.
- The latency from ADC clock to DAC output including all necessary data processing
  - should not exceed a few hundred nanoseconds.
- FPGAs are well suited for this type of hardware due to their the large number of I/O pins, large number of logic cells, and large number of multiplier cores which allow parallel processing of data.
- Goal is to explore the feasibility of realization of digital feedback and feedforward algorithms, complex application algorithms, exception handling and build-in diagnostics

Performance optimization ofr operation at different gradients

- Development of simulation model for vector-sum control of superconducting cavities.
- Implementation of real-time model on high performance computation platform (DSP or FPGA based).
- Performance evaluation with different operating parameters for cavities and controller.

Multichannel downconverter

- Develop low cost and compact high-performance multi-channel downconverter
  - with high degree of linearity, excellent signal to noise ratio, high bandwidth, low offset and LO-IF leakage.
  - Downconverter could make use of commercial analog multipliers such as RF2411 or AD8343.
- Should include
  - remote controlled attenuators at rf inputs
  - RF outputs for transient detection
  - input for rf calibration signals
  - optional: ADCs and FPGA for preprocessing on board and optical Gigalink to connect to main processor for control

Study rad. effect on electronics

- Improve reliability, performance, and lifetime of LLRF system in radiation environment.
- Address hardware and software issues.
- Radiation impact studies include performance degradation in analog circuits, single event effects in digital electronics, total ionizing dose effects leading to complete failure, and displacement damage.
- Protoypes of critical components are produced and studied in radiation environment.

Finite State Machine

- The automation of the LLRF system will be implemented in the framework of a finite state machine (FSM) which is a well established industrial standard.
- The first step will be the definition of the superstates, sub-states, flows, entry-, during-, and exit-procedures, entry conditions, timer and event triggered procedures etc..
- The next step is the description of the applications to be used by the FSM.
- Then the above functionality will be implemented as FSM server in DOOCS and the required application programs will be developed.

Data Management System

- The operation of an accelerator requires calibration of operating parameters, characterization of subsystem components, and documentation of the configuration.
- A feature similar to a database is therefore needed to store and retrieve all the required data.
- Different data types must be available.
- Data entry and access should be userfriendly.
- The data management system should be easy to maintain and support reliable and reproducible operation of the accelerator.

Development of optimal controller

- Modern control theory has developed established methods for the design of optimal controllers.
- Following definitions of the optimal control criteriae these techniques should be applied to synthesize the optimal controller for rf control for superconducting cavities.
- The optimal controller should guarantee best performance and robustness in presence of beamloading, Lorentz force detuning and microphonics while operating close to saturation of the klystron and the performance limit of cavities and couplers.

Exception handling

- Operation of superconducting cavities close to the performance limit will increase the trip rate due to the machine protection system.
- Typical trips include couplers sparcs, cavity quench, klystron sparcs or other faults caused by operation with high power.
- An exception handling system must be implemented with in the rf control system to minimize the trip recovery time. Also unexpected beam loss or other sudden changes in operating parameters must be processed by the exception handler.

Robust RF Gun RF Control

- The normalconducting RF gun requires special control considerations such as low latency in the feedback loop, controller for temperature of the of the rf gun resonator, and interlock scheme.
- Due to the lack of a field probe, the cavity field must be determined by a precision measurement of incident and reflected wave.
- Cavity detuning is measured during field decay as slope of time varying phase with respect to the frequency reference.

N°	MS, Deliverable	Task Name	Anfang	Ende	%
9.1		**Operability and technical performance**	**Do 01.01.04**	**Fr 08.12.06**	**45%**
9.1.1		**Transient detector**	**Do 01.01.04**	**Fr 08.12.06**	**36%**
9.1.1.1		Define requirements	Do 01.01.04	Fr 30.01.04	100%
9.1.1.2		Electronics design	Mo 02.02.04	Fr 27.02.04	100%
9.1.1.3		Build prototype and evaluate	Mo 01.03.04	Fr 30.07.04	100%
9.1.1.4		Final design of detector	Mo 02.08.04	Fr 01.10.04	100%
9.1.1.5		Installation and commissioning	Mo 04.10.04	Mi 09.02.05	100%
9.1.1.6		Test with beam	Mi 09.02.05	Fr 08.12.06	0%
9.1.1.7	Status Repor	**Report on transient detector test**	Fr 08.12.06	Fr 08.12.06	0%
9.1.2		**LLRF Automation**	**Do 01.01.04**	**Fr 23.06.06**	**50%**
9.1.2.1		Dialogue with industrial experts	Do 01.01.04	Fr 27.02.04	100%
9.1.2.2		Develop full specification	Mo 01.03.04	Fr 26.03.04	100%
9.1.2.3		Implement FMS for subsystems	Mo 29.03.04	Fr 29.10.04	100%
9.1.2.4		Test and evaluation	Mo 01.11.04	Mi 23.02.05	100%
9.1.2.5		Implement improvements	Mi 23.02.05	Di 26.04.05	70%
9.1.2.6		Evaluation and acceptance by operators	Di 26.04.05	Fr 23.06.06	0%
9.1.2.7	Status Repor	**Report on LLRF atomization design**	Fr 23.06.06	Fr 23.06.06	0%
9.1.3		**Control optimization**	**Do 01.01.04**	**Fr 13.10.06**	**35%**
9.1.3.1		Specification of system	Do 01.01.04	Fr 02.04.04	100%
9.1.3.2		Conceptual design of controller	Mo 05.04.04	Fr 30.04.04	100%
9.1.3.3		Performance simulation	Mo 03.05.04	Fr 27.08.04	100%
9.1.3.4		Implementation in DSP hardware	Mo 30.08.04	Mi 02.02.05	80%
9.1.3.5		Implementation and tests on TTF	Do 03.02.05	Fr 13.10.06	0%
9.1.3.6	Status repor	**Evaluation of test results**	Fr 13.10.06	Fr 13.10.06	0%
9.1.4		**Exceptional handling routines**	**Do 01.01.04**	**Fr 02.12.05**	**67%**
9.1.4.1		Specification	Do 01.01.04	Fr 23.01.04	100%
9.1.4.2		Design of exceptional handler	Mo 26.01.04	Fr 30.04.04	100%
9.1.4.3		Implementation and test on TTF	Mo 03.05.04	Fr 02.12.05	60%
9.1.4.4	Status Repor	**Report on exceptional handler operatic**	Fr 02.12.05	Fr 02.12.05	0%
9.2		**LLRF cost and reliability study**	**Do 01.01.04**	**Fr 27.10.06**	**44%**
9.2.1		**Cost and reliability study**	**Do 01.01.04**	**Fr 29.09.06**	**47%**
9.2.1.1		Identify cost drivers of present LLRF	Do 01.01.04	Fr 27.02.04	100%
9.2.1.2		Develop cost reduction ideas	Mo 01.03.04	Fr 02.04.04	100%
9.2.1.3		Build prototypes and evaluate	Mo 05.04.04	Fr 21.01.05	100%
9.2.1.4		Final design of LLRF system	Fr 21.01.05	Fr 29.09.06	15%
9.2.1.5	Status Repor	**Complete design of LLRF system for reduced cost**	Fr 29.09.06	Fr 29.09.06	0%
9.2.2		**Radiation damage study**	**Do 01.01.04**	**Fr 27.10.06**	**42%**
9.2.2.1		Identify critical electronics issues	Do 01.01.04	Fr 27.02.04	100%
9.2.2.2		Evaluate TESLA radiation	Mo 01.03.04	Fr 02.04.04	100%
9.2.2.3		Develop tests for components	Mo 05.04.04	Fr 28.05.04	100%
9.2.2.4		Procure and assembles test set up	Mo 31.05.04	Fr 23.07.04	100%
9.2.2.5		Data acquisition from radiation tests	Mo 26.07.04	Fr 29.10.04	100%
9.2.2.6		Analyze results and develop countermeasures	Mo 01.11.04	Mi 09.02.05	80%
9.2.2.7		Implement countermeasures and verify	Mi 09.02.05	Fr 27.10.06	10%
9.2.2.8	Status Repor	**Report on radiation damage studies**	Fr 27.10.06	Fr 27.10.06	0%
9.3		**Hardware**	**Do 01.01.04**	**Mi 01.03.06**	**70%**
9.3.1		**Multichannel downconvertor**	**Do 01.01.04**	**Mi 26.01.05**	**100%**
9.3.1.1		Study and compare technologies	Do 01.01.04	Fr 27.02.04	100%
9.3.1.2		Select optimum PCB design	Mo 01.03.04	Fr 23.04.04	100%
9.3.1.3		Build prototype and evaluate	Mo 26.04.04	Fr 02.07.04	100%
9.3.1.4		Finalize multichannel downconverter	Mo 05.07.04	Fr 03.09.04	100%
9.3.1.5		Determine characteristics	Mo 06.09.04	Mi 26.01.05	100%
9.3.2		**Third generation RF control**	**Do 01.01.04**	**Mo 11.04.05**	**80%**
9.3.2.1		Integrate system generator with VHDL	Do 01.01.04	Fr 30.01.04	100%
9.3.2.2		Complete specification	Mo 02.02.04	Fr 02.04.04	100%
9.3.2.3		Demonstrate simulator	Mo 05.04.04	Fr 04.06.04	100%
9.3.2.4		Final design of RF electronic board	Mo 07.06.04	Fr 28.01.05	90%
9.3.2.5		Evaluate performance	Mo 03.01.05	Mo 11.04.05	20%
9.3.3		**Stable frequency distribution**	**Do 01.01.04**	**Mi 01.03.06**	**50%**
9.3.3.1		Complete specification	Do 01.01.04	Mi 04.02.04	100%
9.3.3.2		Concept ional design of frequency	Do 05.02.04	Fr 05.03.04	100%
9.3.3.3		Build prototype and evaluate	Mo 08.03.04	Fr 06.08.04	100%
9.3.3.4		Final design	Mo 09.08.04	Fr 22.10.04	100%
9.3.3.5		Procurement and assembly of subsystems	Mo 25.10.04	Fr 28.01.05	100%
9.3.3.6		Installation and commissioning	Mo 03.01.05	Fr 18.03.05	30%
9.3.3.7		Performance test with beam	Mo 21.03.05	Mi 01.03.06	0%
9.3.3.8		**Report on new LLRF hardware compor**	Mi 01.03.06	Mi 01.03.06	0%
9.4		**Software**	**Do 01.01.04**	**Fr 06.10.06**	**54%**
9.4.1		**Data management development**	**Do 01.01.04**	**Mi 14.09.05**	**67%**
9.4.1.1		Specification	Do 01.01.04	Fr 30.04.04	100%
9.4.1.2		Conceptional design with DOOCS	Mo 03.05.04	Fr 09.07.04	100%
9.4.1.3		Prototype	Mo 12.07.04	Fr 10.09.04	100%
9.4.1.4		User evaluation	Mo 13.09.04	Fr 05.11.04	100%
9.4.1.5		Finalize design	Mo 08.11.04	Fr 31.12.04	100%
9.4.1.6		Implementation in TTF	Mo 03.01.05	Mi 14.09.05	20%
9.4.1.7		**Report on data management developm**	Mi 14.09.05	Mi 14.09.05	0%
9.4.2		**RF gun control**	**Do 01.01.04**	**Fr 06.10.06**	**47%**
9.4.2.1		Write specification	Do 01.01.04	Fr 30.01.04	100%
9.4.2.2		Design of controller	Mo 02.02.04	Fr 23.04.04	100%
9.4.2.3		Procurement and assembly	Mo 26.04.04	Fr 27.08.04	100%
9.4.2.4		Installation and test	Mo 30.08.04	Fr 06.10.06	30%
9.4.2.5		**Report on RF gun control tests**	Fr 06.10.06	Fr 06.10.06	0%